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# Post Occupancy Evaluation of 23 Newly Renovated Apartments in Copenhagen

## Performance of Ventilation Systems

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### Abstract

*The present article is based on a yearlong post occupancy evaluation of indoor air quality of recently renovated 23 apartments in Copenhagen. The apartments are equipped with novel mechanical ventilation systems. The apartments can be categorised in four, according to the design of ventilation systems. All the ventilation units are equipped with parallel plate cross flow heat exchangers. The analysis in present article is based on the measured indoor quality parameters as well as energy consumptions. Among four different types of ventilation systems, Type 1 is a traditional decentralized ventilation system which works only on two speeds i.e. high airflow rates when kitchen exhaust is on otherwise nominal airflow rates. Type 2 ventilation systems are the decentralized ventilation system with motion sensors in hallways, humidity sensors in rooms and kitchen exhaust hood sensors. Type 3 ventilation system is a centralized ventilation system with the motion sensors in hallways and toilets, humidity sensors in each room, and kitchen exhaust hood sensors. Type 4 ventilation system is a centralized ventilation system with only kitchen exhaust hood sensor. Type 2, Type 3 and Type 4 ventilation systems are also equipped with a newly designed drop type dampers that has a very low pressure drop. The dominant part of the study was based on the comparison of the performance of Type 1 ventilation system with the remaining three.*

**Keywords – post occupancy evaluation; residential apartments; mechanical ventilation systems; drop dampers**

### 1. Introduction

According to the Energy performance of building directive (2002/91/EC) every member state has to reduce the primary energy demands for buildings. Majority of the buildings in Copenhagen are from 1970s or even older. These buildings consume approximately 40% of the total primary energy consumed by the whole Denmark. 75% of the energy consumed by buildings is the share of HVAC systems. Therefore there is a large energy saving potential in energy renovation of existing buildings (Tommerup,

Svendsen 2006). In 2014 three adjacent apartment building from 1970s were renovated. There were 23 apartments in total. These building were located in Frederiksberg within Copenhagen. Before the renovation, apartments were naturally ventilated, whereas after the renovation mechanical ventilation systems were installed in each building. After renovation the buildings were occupied by the tenants in late 2014. The Danish Building Research Institute (SBI) has carried out a follow up study based on post occupancy performance of the all renovated apartments.

## 2. Objective

To analyses the post occupancy performance of the renovated apartment buildings.

## 3. Description of the buildings and associated ventilation systems

Each building has a different type of mechanical ventilation system. The following diagram and table illustrates the building blocks and the associated ventilation systems.

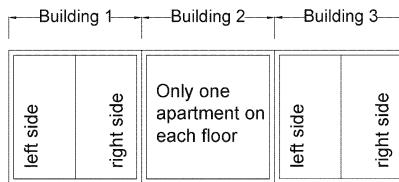


Figure 1 schematic plan of evaluated buildings

Table 1 details of the evaluated buildings

	<b>Building 1</b>		<b>Building 2</b>	<b>Building 3</b>	
	Left side	Right side		Left side	Right side
Area - m <sup>2</sup>	92	62	130	67	73
Height - m	2.7	2.7	2.7	2.7	2.7
No of apt.	5	4	4	5	5
Ventilation system	Type 1	Type 2	Type 3	Type 4	
	De-centralised	De-centralised	Centralised	Centralised	
Control strategy	Conventional with no user control	Variable speed system with limited user control	Variable speed system with limited user control	Variable speed system with no user control	

### Control strategy of the ventilation systems

#### 1) Type 1

The ventilation system is equipped with very basic control system. The mechanical ventilation system runs on two speeds, High speed when the kitchen hood exhaust is on and nominal speed otherwise.

## 2) Type 2

There is one PIR (motion) sensor in hallway, five humidity sensors distributed in rooms and living areas, one kitchen exhaust hood and one control panel in the hallway. There are three modes of the ventilation system:

1. Operation mode
2. Basic mode
3. ECO mode

Operational mode can be activated manually as well as automatically. Whenever relative humidity in the apartments is greater than 60% the ventilation system will be running at the maximum capacity. The operational mode can also be activated to ensure proper ventilation when kitchen hood is on.

Basic mode will ensure low ventilation rates in the apartments. The Basic mode will automatically be activated whenever PIR sensor will not detect any movement in the apartment for 5 hours. The Basic mode will be deactivated whenever PIR will detect any motion in the apartment.

ECO mode will ensure minimum ventilating rates in the apartments. ECO mode can be activated manually through control panel in the hallway. Like-wise ECO mode can be deactivated manually through the control panel.

## 3) Type 3

There is one main PIR sensor in the hallway and one PIR sensor in each toilet, six humidity sensors in rooms and living areas, one control panel in the hallway and one kitchen exhaust hood.

There are three modes of the ventilation system:

1. Operation mode
2. Basic mode
3. ECO mode

Operational mode can be activated manually as well as automatically. Whenever relative humidity in the apartments is greater than 60% or the PIR sensor in the toilet detect motion, the ventilation system will be running at the maximum capacity i.e. control system will calculate new set point for the ventilation rate. The operational mode can be activated to ensure proper ventilation when kitchen hood is on i.e. control system will calculate new set point for the ventilation rate.

Basic mode will ensure low ventilation rates in the apartments. The Basic mode will automatically be activated whenever PIR sensor will not detect any motion in the apartment for 5 hours. The Basic mode will be deactivated whenever PIR will detect any motion in the.

ECO mode will ensure minimum ventilating rates in the apartments. ECO mode can be activated manually through control panel in the hallway. Like-wise ECO mode can be deactivated manually through control.

## 4) Type 4

Only the kitchen exhaust hood is the user oriented part in the ventilation system.

There are two modes of the ventilation system:

1. Operation mode
2. Basic mode

Operation mode can be activated by turning on the hood exhaust i.e. control system will calculate the new set-point.

Basic mode can be activated by turning off the kitchen exhaust i.e. control system will calculate the new set-point.

All ventilation systems are equipped with cross flow plate heat exchangers to recover sensible part of energy from extract air and deliver it to the supplied fresh air. In Type 2, Type 3 and Type 4 ventilation systems, newly developed drop dampers are installed on supply and return ducts on each floor. The drop damper is a newly developed airflow damping technology. These dampers are designed to minimize the running cost and energy consumption, because of low pressure drop, with minimum decibel of noise (Antonsen 2014).

Heating of all the apartments were provided through conventional radiators. However, for Type 3 and Type 4 ventilation system an additional heating coil was provided in the ventilation systems.

#### **4. Methodology**

To analyse the energy performance of buildings the following parameters were measured and logged.

1. Indoor Temperature
2. Indoor Relative humidity
3. Specific airflow rates
4. CO<sub>2</sub> levels
5. Specific electrical energy consumed by the ventilation units
6. Outdoor temperatures
7. Outdoor humidity
8. Heating consumption (not included in the present article).

The hourly indoor temperatures and relative humidity were measured at 3 points in the apartments of Building 1 and Building 2 and at 4 points in the apartments of Building 2. Airflow rates were logged after each 10 minutes through the BMS systems in Type 2, Type 3 and Type 4 ventilation systems. For Type 1, monthly averaged specific airflow rates (ACH) were measured. Hourly CO<sub>2</sub> levels were measured in all apartments. Hourly electrical consumptions were measured by providing an electrical power logger on each ventilation units. Hourly outdoor temperature and humidity was measured in a balcony of an apartment in Building 2.

#### **5. Findings**

The findings in the present article are based on overall performance during the whole year. The detail results regarding the performance in different seasons and the detailed conclusion will soon be published in scientific journals.

The indoor and outdoor parameters in Figure 2 to Figure 6 are presented as box whisker plot. Furthermore mean values are also illustrated as a black dot within the plots. The data in the figures are categorised in *Extract*, *Room* and *Overall*. The *Extract*

shows the average values of the parameters in the toilet and kitchen exhaust ducts. *Room* values are the average room values in the bed rooms, living areas and/or hallways. *Overall* values are the overall average values of the apartment.

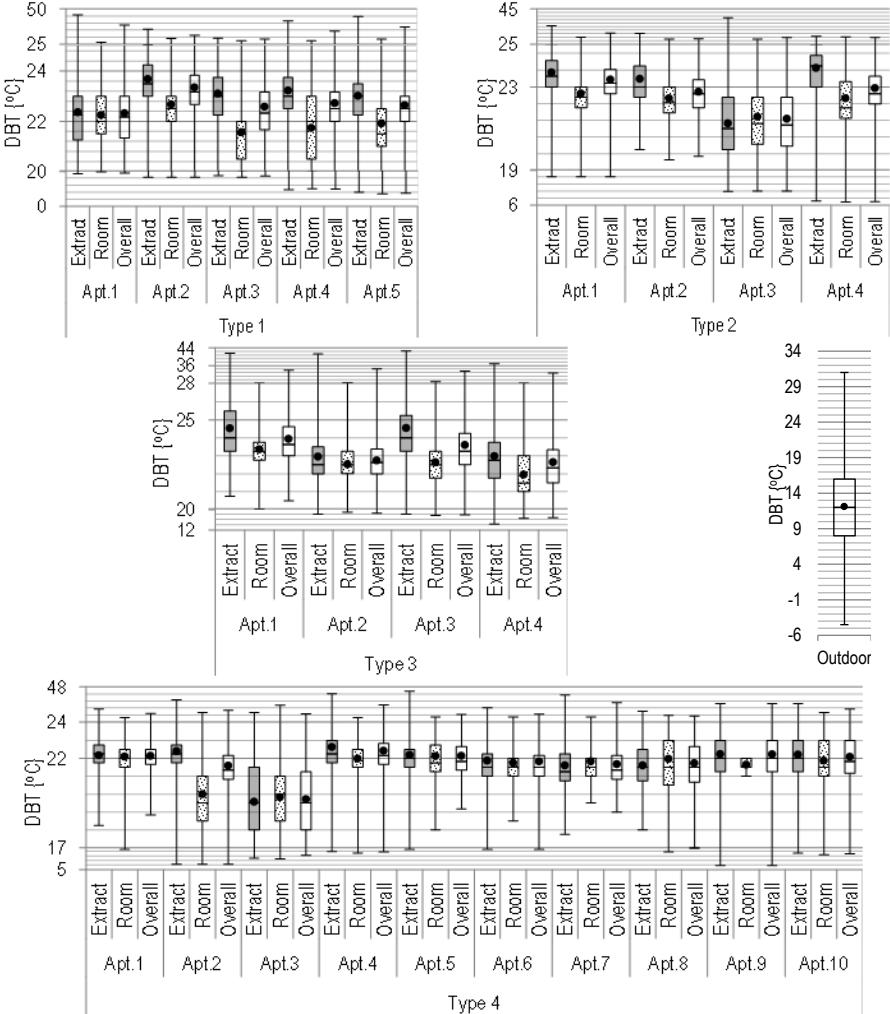


Figure 2 indoor and outdoor temperatures during the monitored period

Dry bulb temperatures (DBT) of all the apartments and outdoor are presented in Figure 2. The averaged value DBT in apartments with Type 1 ventilation systems is 0.4% and 4.3% higher than the corresponding values in apartments with Type 2 and Type 4 ventilation systems respectively. Whereas, the averaged values of DBT in

apartments with Type 1 ventilation system is 2.2% lower than the values in apartments with Type 3 ventilation system. Similarly the humidity levels in apartments with Type 1 ventilation systems is 1.2% higher than the values in apartments with Type 2 systems and 1.8% and 7.4% lower than the values in Type 3 and Type 4 respectively. The humidity levels in the apartments are presented in Figure 3.

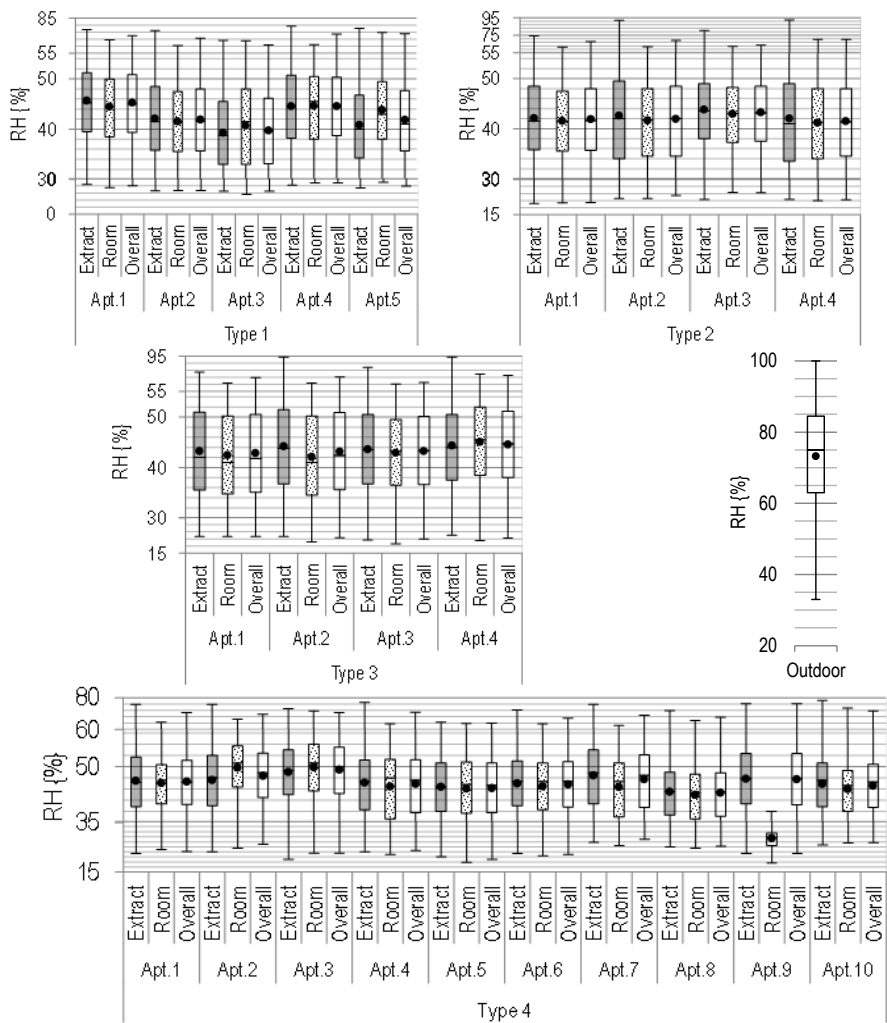


Figure 3 indoor and outdoor relative humidity during the monitored period

There were no standard set points of temperature and humidity levels. The temperatures were controlled through the hydronic radiators and it was up to the tenants

how much they need in the apartment. The difference in relative humidity was mainly due to occupancy levels. The performance of Type 2 and Type 3 ventilation systems will be judge in comparison of humidity levels in the apartments due to the control strategy. Likewise the performance of all ventilation systems will be also judge through the temperature profiles in the kitchen exhaust duct. Any sudden increase in temperature in kitchen exhaust will be considered as cooking time and it will be possible to see the airflow rates at that particular time. However, that detailed analysis is not included in present conference article.

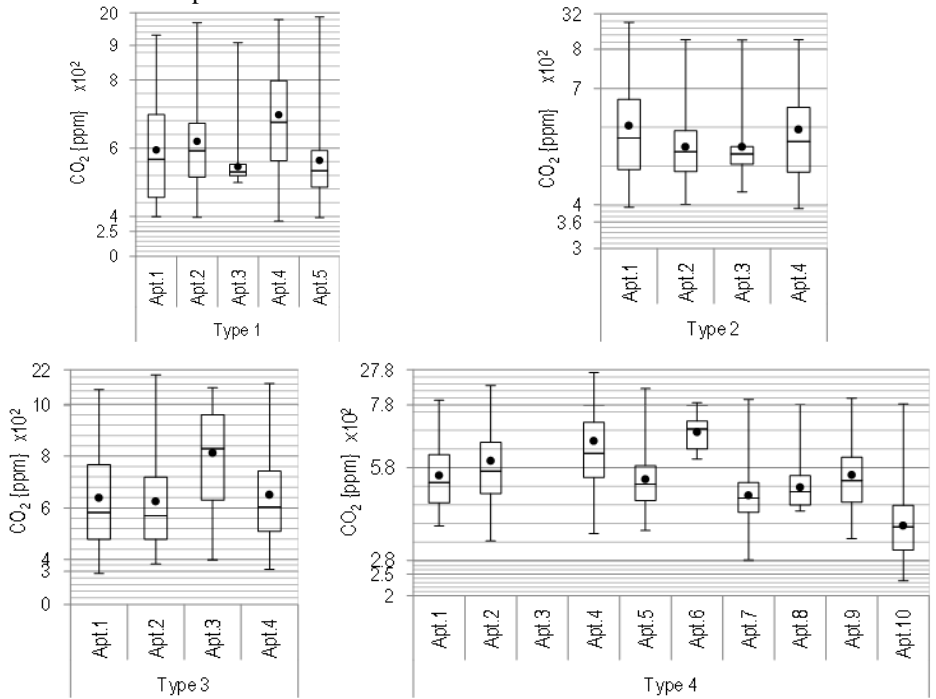


Figure 4 CO<sub>2</sub> levels in the apartments

CO<sub>2</sub> levels in the apartments are shown in Figure 4. Averaged CO<sub>2</sub> levels in apartments with Type 1 systems are 5% and 7.8% higher than the values in apartments with Type 2 and Type 4 systems respectively. Whereas, the CO<sub>2</sub> levels in apartments with Type 1 systems are 12.8% lower than the values in apartments with Type 3 system. The CO<sub>2</sub> levels were not measured continuously throughout the year rather the CO<sub>2</sub> levels were measured during one month in summer and 2 months in winter. Ideally the CO<sub>2</sub> levels should not go significantly higher however there are some instances when the CO<sub>2</sub> levels are more than 1500 ppm. There is a need to evaluate those instances whether the ventilation units were working at that instance or not.



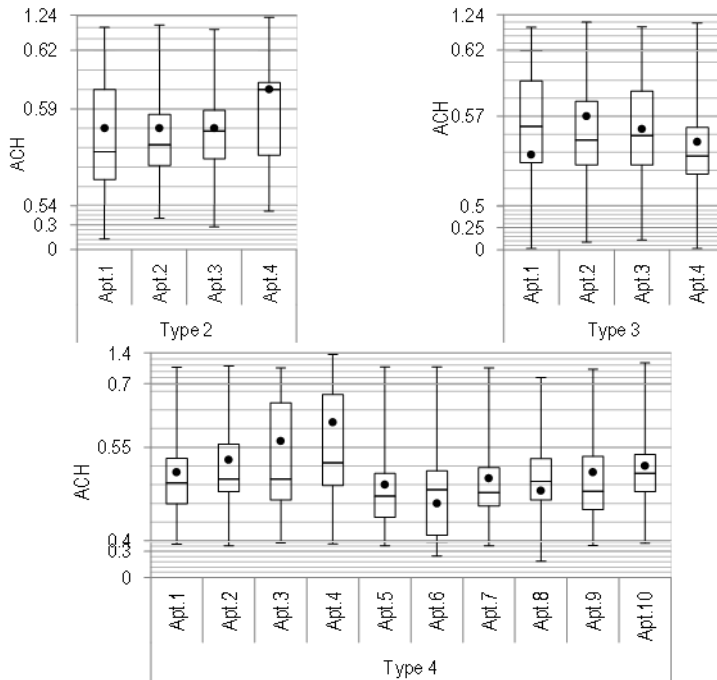


Figure 5 ACH in the apartments

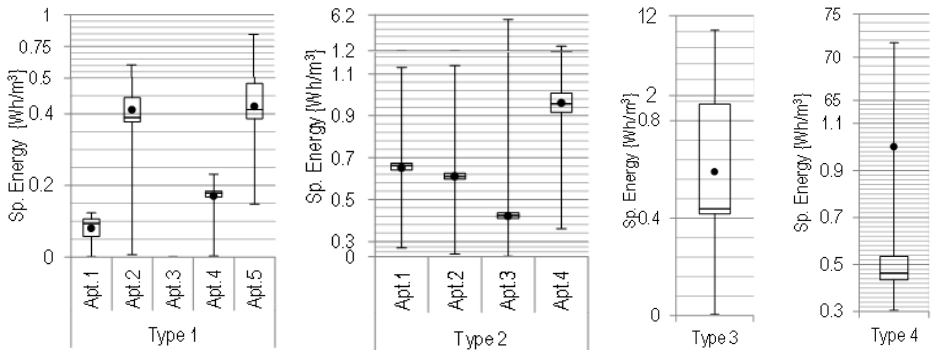


Figure 6 specific electrical energy consumptions of the ventilation units

The airflow rates in apartments with Type 2, Type 3 and Type 4 systems were monitored and logged through BMS system. The airflow rates were measured within drop-dampers. From ventilation rates and volume of the apartment, the specific airflow rates (aka air change rates - ACH) were calculated. As there were no drop-dampers

installed in Type 1 systems and it was not possible to measure and log the airflow rates continuously. Therefore, ACH in apartments with Type 1 systems were measured using tracer gas techniques. The average ACH were 0.6, 0.45, 0.45 and 0.57 of Apt.1, Apt. 2, Apt. 4 and Apt 5 with Type 1 systems. Unfortunately it was not possible to measure the ACH in Apt2. ACH values in the remaining apartments are illustrated in Figure 5.

The averaged values of ACH in apartments with Type 1 systems are 13% and 7.3% lower than the averaged values of apartments with Type 2 and Type 3 systems. Whereas, the values of ACH in apartments with Type 1 systems are 0.5% higher than the values in apartments with Type 4 systems. However, ACH of all apartments were between 0.45 & 0.6.

Specific electrical power consumptions of the ventilation units were calculated by dividing the energy consumptions with the airflow rates. Since the ventilation units are of different types therefore, for comparison purpose specific energy consumption is more appropriate quantity than the electrical power. Interestingly the averaged specific energy consumption of the apartments with Type 1 systems were 164%, 136% and 356% lower than the specific energy consumptions of the apartments of with Type 2, Type 3 and Type 4 systems respectively. The specific energy consumptions of the apartments are illustrated in Figure 6.

## **6. Discussions**

Type 1 is the ventilation system with very basic control i.e. only two speeds i.e. nominal speed and maximum speed when hood is on. In this article Type 1 system considered as a reference system. Remaining three systems are compared with the performance of the reference system. Overall average temperatures of all the apartments were between 21.5°C to 24°C and relative humidity were between 40% and 48%. However, there temperatures and humidity parameters were user defined parameters. No logging was made to insure if the measured temperatures were same as set point temperatures of the radiators or not. All types of ventilation systems were able to deliver minimum required ACH i.e. around 0.5. Similarly, all systems were able to maintain the appropriate CO<sub>2</sub> levels in all the apartments i.e. between 400 and 810. Surprisingly Type 1 systems consumed lesser (down to 356%) energy than the remaining three.

The possible reason of the lesser energy consumed by Type 1 compared with the remaining types is the fact that Type 1 systems were not in continuous operation i.e. they were running intermittently. On the other hand, Type 2, Type 3 and Type 4 were malfunctioning over a significant period of time during the monitoring period. Therefore conclusion cannot be made without filtering the data when the system was malfunctioning.

In the present article only electrical energy consumed by the ventilation units are used to compare the energy performances of different apartments. Heating energy is also necessary to include in the calculation to analyse the energy performance of the apartments. Heating energy consumption will also be included in the upcoming results.

Likewise, the findings in the present article are based on overall performance of the whole year. It is necessary to analyse the performance based on particular season e.g.

during winter and when kitchen hood is off etc. These kind of detailed results are under development and will be published soon.

## **7. Conclusions**

The present article was a preliminary finding from an ongoing project. From initial findings it was observed that regardless of the type, all mechanical ventilation systems were capable of providing appropriate indoor air quality. The only parameter that was significantly different was the energy consumption. The conventional system consumed less energy than the systems with several automatic control sensors.

## **Acknowledgment**

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